MADROÑO, Vol. 47, No. 1, pp. 61–67, 2000

ESTIMATED AGES OF SOME LARGE GIANT SEQUOIAS: GENERAL SHERMAN KEEPS GETTING YOUNGER

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ABSTRACT

Using a method that combines information on tree size with growth rates determined from relatively short increment cores, I estimated the ages of several of the largest living *Sequoiadendron giganteum* (Lindley) Buchholz. Compared to the longest-lived *S. giganteum* known, which was at least 3266 years old, most of the large sequoias analyzed here were relatively young, with estimated ages of only 1650 to 2150 years. Thus, contrary to common supposition, the largest *S. giganteum* generally owe their great size to rapid growth, not to exceptional age. However, two of the largest *S. giganteum* were substantially older, with estimated ages of 2850 and 2890 years. There is a high probability that some *S. giganteum* living today are older than the oldest *S. giganteum* yet discovered.

People have long been fascinated by the great size and longevity of *Sequoiadendron giganteum* (Lindley) Buchholz (giant sequoias), which grow naturally only in isolated groves on the western slope of California's Sierra Nevada. *Sequoiadendron giganteum* are the world's largest trees, reaching a maximum known bole volume of nearly 1500 m^3 (Hartesveldt et al. 1975; Flint 1987 and in press). Precise cross-dating of tree rings on cut stumps has shown that sequoias can reach at least 3266 years in age (R. Touchan personal communication), making *S. giganteum* the third longest-lived, non-clonal tree species known, exceeded only by *Pinus longaeva* Bailey (bristlecone pine, 4844 years) of western North America's Great Basin (Currey 1965) and *Fitzroya cupressoides* (Molina) Johnston, (alerce, 3613 years) of Chile and Argentina (Lara and Villalba 1993).

Here I present age estimates for some large, well-known *S. giganteum*, thereby addressing one of the most frequently-asked questions about famous *S. giganteum*—namely, "how old is this tree?" I additionally address two questions regarding *S. giganteum* sizes and ages. First, are the largest *S. giganteum* so massive because they are exceptionally old, as is often presumed, or because they have grown particularly rapidly? Second, are there likely to be any *S. giganteum* alive today that are older than the longest-lived *S. giganteum* yet known, which is known only from a cut stump?

These questions are difficult to answer because the only way to precisely determine the age of living *S. giganteum* is to crossdate tree rings on increment cores that intersect the tree's pith (Stokes and Smiley 1968). However, the tremendous girth of large *S. giganteum* usually makes it impossible to reach their piths with hand-driven increment borers. Power increment borers with very long bits can sometimes be used to obtain cores that reach the pith (Echols 1969; Johansen 1987), but have several disadvantages, which include unacceptably large holes left in the trees, poor quality of many of the cores extracted, and unacceptable use of noisy power tools on and around popular and frequently-visited *S. giganteum*.

I therefore estimated the ages of several large *S. giganteum* using a method that takes advantage of information from partial increment cores (cores that fall well short of a tree's pith). The derivation and testing of the method is described in detail elsewhere (Stephenson and Demetry 1995). Unlike previous attempts to estimate the ages of large *S. giganteum* (e.g., Douglass 1946; Hartesveldt et al. 1975), this method has been tested on hundreds of *S. giganteum* stumps, does not systematically over- or underestimate tree ages, and offers confidence intervals on the final age estimates.

METHODS

Choice of individual Sequoiadendron giganteum *for analysis.* The primary criteria for choosing individual *S. giganteum* for analysis were (1) the *S. giganteum* were among the largest known, and (2) the cores and other data needed for age estimation were already available (that is, no *S. giganteum* was to be cored solely for the purpose of this study). Specifically, for a given *S. giganteum* to be included, original increment cores or the necessary measurements from those cores had to be available, along with measurements of the tree's bark thickness and diameter at the height at which the cores were taken. These data requirements limited the pool of *S. giganteum* available for analysis. While many large *S. giganteum* have been cored for studies of human impacts (Hartesveldt 1962, 1965), ring-width chronology development (Brown et al. 1992; Hughes et al. 1996), climatic reconstructions (Hughes and Brown 1992), forest dynamics studies

TABLE 1. *SEQUOIODENDRON GIGANTEUM* SELECTED FOR ANALYSIS (SIZE RANKS AND BOLE VOLUMES ARE FROM FLINT IN PRESS AND PERSONAL COMMUNICATION).

Tree name	Size rank (by volume)	Bole volume (m^3)	Location
General Sherman	1	1487	Giant Forest, Sequoia National Park
Washington	2	1355	Giant Forest, Sequoia National Park
General Grant	3	1320	General Grant Grove, Kings Canyon National Park
Boole	7	1202	Converse Basin Grove, Giant Sequoia National Monument
Grizzly Giant	27	963	Mariposa Grove, Yosemite National Park
Cleveland	36	887	Giant Forest, Sequoia National Park
Sentinel	Not ranked	790	Giant Forest, Sequoia National Park

NOTE: Future discoveries of previously unrecognized large sequoias will probably change the ranking of sequoias smaller than the Boole tree. For example, the fourteenth largest sequoia known (the Ishi Giant of Kennedy Grove) was identified only in 1993 (Willard 1994; Flint personal communication).

(Stephenson 1994), and fire history reconstruction (Swetnam 1993), only a limited subset of those *S. giganteum* have associated records of diameter at core height. Diameter at core height is essential for age estimation (Stephenson and Demetry 1995), and cannot be estimated readily from published diameters at breast height of individual *S. giganteum*. Cores are rarely taken exactly at breast height, and sequoia bole diameter usually changes rapidly with increasing distance from breast height.

The following seven large *S. giganteum* were selected for analysis (Table 1). The General Sherman, Washington, and General Grant trees are the world's three largest trees, with the General Sherman and General Grant trees being among the most heavily visited of all *S. giganteum*. The Boole tree is the seventh largest, and is well-known as being the largest sequoia on lands managed by the U.S. Forest Service. The Grizzly Giant is heavily visited because of its craggy appearance and status as one of the two largest *S. giganteum* in Yosemite National Park, whereas the Cleveland tree is a lesser-known and seldom-visited tree in Sequoia National Park. Finally, the Sentinel tree is a well-known sequoia beside the road at the southern entrance to Giant Forest in Sequoia National Park.

The General Sherman, Washington, General Grant, Grizzly Giant, and Cleveland trees all were cored by R. J. Hartesveldt and his colleagues for various studies during the late 1950's and early 1960's. All cores and data sheets for these trees are archived at Sequoia National Park, except I was unable to locate the original core for the Washington tree, and therefore relied exclusively on Hartesveldt's ring measurements for that tree. The Boole tree was cored by researchers from the University of Arizona in 1992; those data were kindly supplied by L. S. Mutch. Finally, the Sentinel tree was cored by V. G. Pile and me in 1998 at the request of National Park Service staff, who wished to have an age estimate for displays near the tree.

Estimating tree ages. I estimated ages of these seven *S. giganteum* following Stephenson and Demetry's (1995) approach, which combines knowledge of tree size with information gained from partial increment cores. The derivation and biological basis of this approach are too lengthy to repeat here; interested readers are therefore referred to Stephenson and Demetry (1995). When tested on 231 sequoia stumps up to 3200 years old and 6.5 m in diameter, this approach gave age estimates that were within 10% of actual age 62% of the time, and within 25% of actual age 98% of the time, assuming that two 60-cm increment cores are available for analysis; fewer or shorter cores gave less precise estimates. This level of precision is a substantial improvement over that of previously published methods, which estimated tree age from diameter alone, by assuming that basal area increment is constant through time, or by linear extrapolation of growth rates from the innermost portion of an increment core (Stephenson and Demetry 1995).

Sequoia age in years, *a,* was estimated according to the following equation,

$$a = (c - 100) + \frac{100r^d}{r^d - (r - g)^d} \qquad [1]$$

where c is the full ring count of a partial increment core; g is the length of the innermost 100 rings of the increment core; r is the length g plus the length of the section of bole radius (extending to the tree's pith) that was not sampled by the increment core; and d is given by the following equation:

$$d = 0.230 + 0.759(100/g_{mm}) + 1.27r - 0.848r^2 + 0.159r^3 \qquad [2]$$

Units for g and r are meters, whereas g_{mm} is the length of the innermost 100 rings of the increment core in mm. For reasons discussed in Stephenson and Demetry (1995), if r exceeded 3 m, $r = 3$ m was substituted into eq. 2 for calculating d.

A sequoia's pith usually is not at the geometric center of its bole. However, we typically have no way of determining the location of a living tree's pith, and therefore cannot directly measure the val-

TABLE 2. CONFIDENCE INTERVALS FOR *S. GIGANTEUM* AGE ESTIMATES BASED ON DIFFERENT NUMBERS AND LENGTHS OF INCREMENT CORES (FROM STEPHENSON AND DEMETRY 1995).

	Two 60-cm cores	One 60-cm core	Two 30-cm cores	One 30-cm core
50% confidence interval	−6.9 to 9.0	−8.4 to 9.4	−14.1 to 11.1	−13.0 to 11.8
95% confidence interval	−23.7 to 19.5	−36.7 to 19.7	−45.8 to 26.4	−48.2 to 27.5

NOTE: The intervals are expressed as percentage of estimated sequoia age. For example, the −23.7% listed as one endpoint of the 95% confidence interval for two 60-cm cores means that 2.5% of the time, actual tree age will be more than 1.237 times estimated tree age. (Rephrased, 2.5% of the time estimated sequoia age will be at least 23.7% less, expressed in terms of estimated sequoia age, than actual sequoia age.) The 19.5% listed as the other endpoint of the interval means that 2.5% of the time, actual tree age will be less than 0.805 times estimated tree age.

ue of r associated with a particular increment core. Therefore r was estimated as described by Stephenson and Demetry (1995). First, tree radius was calculated as half of tree diameter (determined by diameter tape) at the height at which the increment core was taken. Average bark thickness, determined by probes at several location around the bole, was then subtracted to determine tree radius inside the bark. From this, the length of the increment core, excluding the core's innermost 100 rings, was subtracted, yielding an estimate of r.

Because increment cores shrink as they dry, the wet length of a core must be known for the most accurate application of eqs 1 and 2. However, for most of the *S. giganteum* analyzed here (the Sentinel tree being the one exception), wet lengths of cores were not recorded. My colleagues and I (unpublished data) have found that the average shrinkage of hundreds of sequoia cores was about 2%. Thus, when the wet length of a core was not recorded, it was estimated by multiplying the core's dry length by 1.02.

To improve accuracy, when several cores were available from a sequoia, a given core's location on the bole had to be separated from that of the other cores by at least 90° of circumference to be included in the age estimation (Stephenson and Demetry 1995). Tree age at height cored was estimated by averaging the age estimates based on the individual cores (Stephenson and Demetry 1995).

Some of the data used to estimate sequoia ages came from *S. giganteum* cored several decades ago. It was therefore necessary to account for the number of years that have passed since a sequoia was cored. Because, for convenience, I wished to estimate all sequoia ages relative to the year 2000, I subtracted the year in which a core was taken from 2000, then added the result to estimated tree age.

The method outlined above only estimates sequoia age at the height at which the cores were taken. However, accounting for the time it took a tree to grow to the height cored potentially can add decades to the tree's estimated age. To account for height growth, I multiplied the height of the core above ground level (in m) by $178x^{-0.957}$, where x is the (estimated) cumulative width, in mm, of the 10 rings that abut the tree's pith. This empirical factor scales height growth to radial growth, and was derived from ring measurements of 41 smaller *S. giganteum* which my colleagues and I cored to the pith both near ground level and near breast height (see Agee et al. 1986 for a similar approach). However, because there is no way of knowing the actual cumulative width of the 10 rings that abut the pith of the large *S. giganteum* analyzed here, I assumed that the width was 27.5 mm, based on the average from measurements of more than 450 sequoia stumps (Table A in Huntington 1914). Thus, I assumed that large *S. giganteum* took $178 \times (27.5)^{-0.957} = 7.5$ years to grow each meter taller until core height was reached. However, with the exception of the Sentinel and Grizzly Giant trees, core heights were not recorded. I therefore estimated core heights for the other trees based on conversations and correspondence with individuals involved in the corings (H. S. Shellhammer for the General Sherman, Washington, General Grant, and Cleveland trees, and R. Adams and L. Mutch for the Boole tree).

Confidence intervals. Stephenson and Demetry (1995) showed that as both the number and length of increment cores increase, confidence in sequoia age estimates also increases (Table 2). However, the numbers and lengths of cores used did not always fall neatly into the categories in Table 2. To determine confidence intervals, core lengths were therefore rounded to the nearest category shown in Table 2 (either 30 or 60 cm). In two cases (the General Sherman and General Grant trees), three cores rather than two were used. However, since confidence is improved relatively little by increasing core number (it is improved more by increasing core length; Table 2), confidence intervals for only two cores were used.

The number of years elapsed between the year in which a tree was cored and the year 2000 was then added to the endpoints of the tree's confidence intervals, as was the estimated number of years it took each sequoia to grow to the height at which it was cored. Admittedly, the latter step does not change a sequoia's age confidence intervals to reflect the uncertainty associated with estimating the number of years it took a sequoia to grow to the height cored. However, uncertainty added at this

TABLE 3. DATA USED TO ESTIMATE THE AGES OF THE SELECTED *S. GIGANTEUM*. [a] Side of tree from which core was taken. [b] Confidence intervals (see Table 2) are: 1 × 30, one 30-cm increment core; 2 × 30, two 30-cm cores; 1 × 60, one 60-cm core; 2 × 60, two 60-cm cores. [c] Estimated from length of innermost 154 rings. [d] Estimated from length of innermost 280 rings.

Tree	Core[a]	Diameter at core height (m)	Bark thick-ness (m)	Wet length of full core (m)	Wet length of innermost 100 rings of core (m)	Ring count of full core	Height of core above ground (m)	Year cored	Confidence interval used[b]
General Sherman	South	7.325	0.127	0.387	0.148	317	1.6	1964	2 × 30
	Northwest	7.325	0.127	0.365	0.156	249	1.6	1964	
	East	7.325	0.127	0.352	0.120	315	1.6	1964	
Washington	—	7.858	0.152	0.291	0.091	325	1.4	1963	1 × 30
General Grant	Southeast	6.705	0.203	0.375	0.259	146	2.0	1964	2 × 30
	West	6.705	0.203	0.376	0.180	233	2.0	1964	
	North	6.705	0.203	0.378	0.139	293	2.0	1964	
Boole	B (Northwest?)	7.45	0.090	0.418	0.124[c]	259	1.4	1992	1 × 60
	C (Northeast?)	7.45	0.090	0.639	0.159[d]	386	1.4	1992	
Grizzly Giant	Southwest	6.621	0.127	0.289	0.175	206	3.05	1958	2 × 30
	East	6.621	0.127	0.266	0.148	175	3.05	1958	
Cleveland	—	5.613	0.127	0.347	0.045	598	1.6	1964	1 × 30
Sentinel	Northeast	6.399	0.073	0.515	0.099	366	2.56	1998	2 × 60
	Southwest	6.399	0.073	0.556	0.128	333	2.04	1998	

stage is small compared to the uncertainty of estimating the tree's age at core height.

Statistics on the longest-lived sequoia known. As a yardstick for interpreting results, I used the age and size of the longest-lived sequoia known—a cut stump in Converse Basin, Giant Sequoia National Monument, designated CBR26 by its discoverers (R. Touchan and E. Wright of the University of Arizona's Laboratory of Tree-Ring Research). Touchan has precisely crossdated 3207 rings on the stump. It is missing much of its sapwood, so the outermost ring dates to 1834. However, the extensive logging of Converse Basin Grove occurred between 1893 and 1908 (Johnston 1983; Willard 1994). Thus, at least 59 years of sapwood are missing, and the tree therefore was at least 3266 years old when it was cut. (It is unlikely that the tree exceeded 3290 years old, including the time it took the tree to grow to the height sampled by Touchan and Wright.) The stump is relatively small: 5.8 m in diameter near ground level and 4.3 m in diameter at the cut surface 2.2 m above ground level (R. Touchan personal communication). Even with sapwood and bark intact, the tree's diameter at 2.2 m above ground level was probably less than 5 m when it was cut, much smaller than any of the trees analyzed here (Table 3). While we will never know the volume of the living CBR26, it is clear that many hundreds of *S. giganteum* alive today (probably well over one thousand) are larger than CBR26 was before it was cut (e.g., see Appendix 1 in Stohlgren 1991).

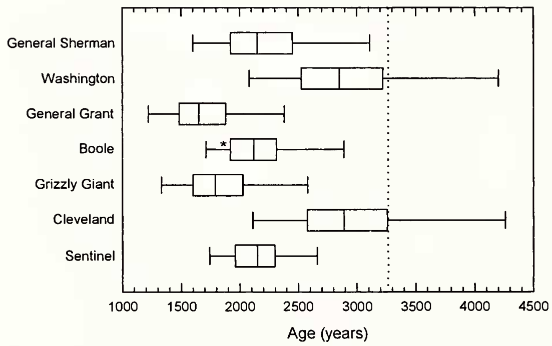

FIG. 1. Estimated ages of selected *S. giganteum* in the year 2000, with associated confidence intervals. The vertical line within each horizontal box indicates that tree's estimated age. The ends of each box delimit the 50% confidence interval for that tree's age, whereas the "whiskers" extending from each box delimit the 95% confidence interval. The dotted vertical line at 3266 years indicates the age of the oldest sequoia yet discovered (see the text). Because the innermost ring of a long core taken within a fire scar cavity at the base of the Boole tree has been crossdated to A.D. 143 by E. Wright of the University of Arizona (L. Mutch personal communication), the Boole tree is at least 1858 years old, as indicated by the asterisk.

RESULTS

Table 3 presents the data used to estimate the ages of the seven large *S. giganteum*. Estimated ages ranged from 1650 years for the General Grant tree to 2890 years for the Cleveland tree (Fig. 1), averaging 2230 years. Though all of these *S. giganteum* were much larger than CBR26, the longest-lived sequoia known, five had estimated ages at least 1000 years younger than CBR26 (Fig. 1). In fact, the third-largest living sequoia (the General Grant tree) is estimated to be little more than half as old as CBR26. Additionally, CBR26's age lies well outside of the high end of the 95% confidence intervals of the five *S. giganteum* (Fig. 1).

While there are exceptions (namely, the Washington and Cleveland trees), the largest living *S. giganteum* generally owe their great bulk to rapid growth, not to extraordinary age. For example, average ring width from the cores of the (estimated) youngest sequoia (the General Grant tree, 1.82 mm) was more than three times that of the (estimated) oldest sequoia (the Cleveland tree, 0.58 mm). This notion is further supported by Huntington's (1914) age data from more than 450 sequoia stumps (the accuracy of which is discussed in Stephenson and Demetry 1995). Huntington's ten largest stumps averaged 6.0 m in diameter inside the bark, but only 1842 years old by direct ring count (the largest was 6.5 m in diameter but only 1347 years old). In sharp contrast, his ten oldest stumps averaged only 4.9 m in diameter inside the bark, but 2822 years old—1 m less in diameter but nearly 1000 years older. Membership in the two groups of stumps was almost mutually exclusive; only one stump was both one of the ten largest and one of the ten oldest (see Fig. 1 in Stephenson and Demetry 1995). Thus, for whatever reason, *S. giganteum* that reach great age tend to have grown relatively slowly.

Figure 1 indicates that there is a 25% probability that the Cleveland tree is older than CBR26, and a similar probability that the Washington tree is older. The probability that at least one of these two living trees (Cleveland or Washington) is older than CBR26 therefore is roughly $1 - (0.75)^2$, or 44%—nearly even odds. Given that the seven *S. giganteum* examined here are only a small sample of all potentially old, living *S. giganteum* (likely candidates would number well over one thousand), it seems highly likely that some *S. giganteum* living today exceed the age of CBR26.

Discussion

There has been a long-standing belief that the largest *S. giganteum* are the oldest. This is well illustrated by tracing the history of age estimates for the General Sherman tree, the world's largest tree. By the early 20th century, careful ring counts and crossdating had identified a handful of sequoia stumps more than 3000 years old, the oldest being about 3200 years old (Huntington 1914; Douglass 1919, 1945). (John Muir's reported count of 4000 rings on the "Muir Snag" in 1875 has not been repeated and was almost certainly in error [Flint 1987], and other early claims of up to 11,000 rings counted on stump tops [Jordan 1907] cannot be taken seriously.) Since none of these old stumps approached the great size of the General Sherman tree, most natural historians concluded that the General Sherman tree must be more than 3500 years old (e.g., Fry and White 1930). Stewart (1930) believed that the General Sherman tree was about 4000 years old, though he reported that an estimate based on "average number of rings counted . . . in charred fragments from parts of the [General Sherman tree's] burned trunk, in connection with the actual counts of rings of felled trees . . . which have grown under conditions and situation similar to those of the Sherman tree" yielded an age of 5200 years. Popular publications, such as a 1931 program for a play performed among the sequoias not far from the General Sherman tree, tended to be more extravagant, proclaiming the tree to be 6000 years old (see also Hartesveldt et al. 1975). Ironically, the aforementioned play took place less than two months before the first quantitative estimate of the General Sherman tree's age based on increment cores, by A. E. Douglass.

Douglass, the founder of the modern science of dendrochronology, obtained six short cores from the General Sherman tree in 1931 (the year is mistakenly given as 1935 in Douglass [1946]). He deemed two of the cores to be good enough to use for age estimation, finding that average ring width at 4.6 m above ground level was 0.81 mm. This ring width is less than that of Hartesveldt's cores (Table 3) because it comes from a height where the General Sherman tree's bole is narrower. Douglass stated that "[t]hese are ring sizes which, in relation to the total size of the tree and the probable rate at which rings increase in size toward the center, supplied an estimate of the age of the tree of 3500 years plus or minus 500 years" (Douglass 1946). I have found no quantitative description of how Douglass accounted for "the probable rate at which rings increase in size toward the [tree's] center."

To shed light on Douglass' age estimate, I applied the approach outlined in this paper to his data. Douglass' data yield an age of only 2380 years for the General Sherman tree in 1931, or 2450 years in 2000 (rounded to the nearest decade). This latter estimate is only 300 years older than the estimate based on Hartesveldt's cores (Fig. 1), and is well within that estimate's 95% confidence interval. However, I judge the estimate based on Hartesveldt's cores to be much more reliable than that based on Douglass' cores. Specifically, the estimate based on Hartesveldt's cores required that fewer key parameters be estimated (such as the diameter of the General Sherman tree at 4.6 m above ground level in 1931, needed for using Douglass' data), and was based on three cores widely spaced around the tree's bole, each of which was nearly twice as long as the longest of Douglass' two adjacent cores.

In contrast, an age estimate based on linear extrapolation of Douglass' ring-width data, assuming no change in ring width toward the General Sherman tree's center (an unrealistic assumption), would yield an age of 3790 years in 1931. Thus, Douglass' estimate of 3500 (±500) years apparently was little different from an estimate based on a simple linear extrapolation, and did not adequately consider the increase in ring widths toward the pith.

Douglass' age estimate was widely quoted (and sometimes exaggerated) from 1931 until the 1960's, when Hartesveldt et al. (1975) radically revised the estimate downward. Unlike Douglass, Hartesveldt and his colleagues explicitly stated their assumption as to how ring widths change within a tree: they assumed that basal area increment is constant (that is, trees add a constant amount of basal area each year). This is equivalent to substituting $d = 2$ into eq. 1 (Stephenson and Demetry 1995). Hartesveldt's notes (archived at Sequoia National Park) show that when he strictly adhered to this assumption, he estimated that in 1964 the General Sherman tree was only about 1600 years old. However, Hartesveldt's examination of growth patterns on sequoia stumps measured by Huntington (1914) indicated that strict adherence to this assumption sometimes underestimated the ages of *S. giganteum* (Hartesveldt et al. 1975). Thus, apparently based on a combination of assumed constant basal area increment and judicious comparisons with Huntington's data, Hartesveldt and his colleagues (1975) cautiously stated that the General Sherman tree "... is less than 2500 years old." According to my calculations using their original cores and data, their statement has a more than 75% probability of being true (Fig. 1).

As careful as Hartesveldt et al. (1975) may have been in stating that the General Sherman tree was less than 2500 years old, the National Park Service, perhaps unable to bear such a precipitous decline in the tree's age, instead adopted 2500 years as the midpoint for a range encompassing the tree's estimated age. At the time of this writing, Park literature and the plaque at the General Sherman tree stated that the tree's estimated age was "2300–2700 years." Additionally, a popular book authored by Hartesveldt's colleagues (Harvey et al. 1981) dropped the qualifier "less than," stating instead that the tree "... is about 2,500 years old" (though a table on the same page gives the General Sherman tree's age as "2,500–3,000" years!). The most recent estimate of the General Sherman tree's age—2150 years (Fig. 1)—is most closely aligned with Hartesveldt et al.'s (1975) original statement that the tree is less than 2500 years old.

The relative youth of other famous *S. giganteum* may come as a disappointment to some. For example, the decline in the estimated age of the Grizzly Giant tree has been even more precipitous than that of the General Sherman tree. Clark (1910) reported that the Grizzly Giant had been growing so slowly over the last few centuries that its rings (presumably observed inside of a fire scar cavity) were "as thin as wrapping paper, too fine to be counted with the unaided eye." (On the contrary, measured ring widths [Table 3] and measured tree volume changes [W. Flint personal communication] both indicate that the tree has been growing quite rapidly.) Comparing these purported ring widths with those of some fallen *S. giganteum*, Clark concluded that "the Grizzly Giant must be not less than six thousand years old," and that the tree was probably the oldest living thing on earth. Other early age estimates placed the Grizzly Giant at a more modest 3800 years old, while Hartesveldt et al. (1975) later suggested that the tree "... is perhaps only 2500 years old." At the time of this writing, the National Park Service reported the age of the Grizzly Giant as 2700 years. However, I estimate the tree to be only about 1790 years old (Fig. 1), and that the probability of it being at least 2700 years old is less than 2%. Hartesveldt and his colleagues (1975) offered solace to those disappointed by the suggestion that certain large *S. giganteum* might be younger than expected: "... this [discovery] effects a change only in superlatives; the world's largest trees are the world's fastest-growing trees."

Some readers may be disappointed by the broad confidence intervals associated with age estimates in Figure 1. There is a great deal of uncertainty in estimating the ages of individual large *S. giganteum*, largely due to relatively abrupt and sustained changes in ring widths in the part of the bole not sampled by increment cores, and therefore invisible to us (Stephenson and Demetry 1995). Such changes in growth rates are due to unpredictable, site-specific events in the past, such as occasional, localized high-intensity fires (e.g., Mutch and Swetnam 1995). Thus, though Figure 1 suggests that the General Sherman and Sentinel trees are the same age (2150 years), the broad confidence intervals additionally suggest that this correspondence is most likely a meaningless coincidence. However, most of the confidence intervals in Figure 1 are based on relatively short cores. Confidence intervals could be tightened somewhat in the future by taking longer cores and, in the case of the Washington and Cleveland trees, more cores.

Acknowledgments

I thank R. Touchan of the University of Arizona's Laboratory of Tree-Ring Research for graciously supplying data on CBR26, and L. S. Mutch for supplying data on the Boole tree. Additional thanks go to V. G. Pile (USGS), who helped me core the Sentinel tree, and D. J. McGraw (University of San Diego), who sent copies of Douglass' original notes and correspondence on the General Sherman tree, and who inspired me to complete this work. A. Caprio, M. Crapsey, W. Flint, J. Keeley, D. McGraw, H. Shellhammer, D. Shenk, R. Touchan, W. Tweed, and two reviewers provided helpful comments on the manuscript.

Literature Cited

Agee, J. K., M. Finney, and R. de Gouvenain. 1986. The fire history of Desolation Peak. Cooperative Parks Study Unit, University of Washington, Seattle. Final contract report to the National Park Service, Cooperative Agreement CA-9000-3-0004.

Brown, P. M., M. K. Hughes, C. H. Baisan, T. W. Swetnam, and A. C. Caprio. 1992. Giant sequoia ring-width chronologies from the central Sierra Nevada, California. Tree-Ring Bulletin 52:1–14.

CLARK, G. 1910. The big trees of California. Yosemite Valley, CA.

CURREY, D. R. 1965. An ancient bristlecone pine stand in eastern Nevada. Ecology 46:564–566.

DOUGLASS, A. E. 1919. Climatic cycles and tree growth, Vol. I. Carnegie Institute of Washington Publication No. 289, Washington D.C.

———. 1945. Survey of sequoia studies. Tree-Ring Bulletin 11:26–32.

———. 1946. Sequoia survey—III: miscellaneous notes. Tree-Ring Bulletin 13:5–8.

ECHOLS, R. M. 1969. Powered drive for large increment borers. Journal of Forestry 67:123–125.

FLINT, W. D. 1987. To find the biggest tree. Sequoia Natural History Association, Three Rivers, CA.

———. In press. To find the biggest tree, 2nd ed. Sequoia Natural History Association, Three Rivers, CA.

FRY, W. AND J. R. WHITE. 1930. Big trees. Stanford University Press, CA.

HARTESVELDT, R. J. 1962. The effects of human impact upon *Sequoia gigantea* and its environment in the Mariposa Grove, Yosemite National Park, California. Ph.D. dissertation. University of Michigan, Ann Arbor.

———. 1965. An investigation of the effect of direct human impact and of advanced plant succession on *Sequoia gigantea* in Sequoia and Kings Canyon National Parks, California. Report on contract number 14-10-0434-1421, USDI National Park Service, San Francisco, CA.

———, H. T. HARVEY, S. H. SHELLHAMMER, AND R. E. STECKER. 1975. The giant sequoia of the Sierra Nevada. U.S. Department of the Interior, National Park Service, Washington D.C.

HARVEY, H. T., H. S. SHELLHAMMER, R. E. STECKER, AND R. J. HARTESVELDT. 1981. Giant sequoias. Sequoia Natural History Association, Three Rivers, CA.

HUGHES, M. K., R. TOUCHAN, AND P. M. BROWN. 1996. A multimillennial network of giant sequoia chronologies for dendroclimatology. Pp. 225–234 *in* J. S. Dean, D. M. Meko, and T. W. Swetnam (eds.), Tree rings, environment, and humanity. Proceedings of the International Conference. Radiocarbon, Department of Geosciences, The University of Arizona, Tucson, AZ.

——— AND P. M. BROWN. 1992. Drought frequency in central California since 101 B.C. recorded in giant sequoia tree rings. Climate Dynamics 6:161–167.

HUNTINGTON, E. 1914. The climatic factor as illustrated in arid America. Carnegie Institute of Washington Publication No. 192, Washington D.C.

JOHANSEN, R. W. 1987. Taking increment cores with power tools. Southern Journal of Applied Forestry 11: 151–153.

JOHNSTON, H. 1983. They felled the redwoods. Trans-Anglo Books, Glendale, CA.

JORDAN, D. S. 1907. The alps of the King-Kern divide. A. M. Robertson, San Francisco, CA.

LARA, A. AND R. VILLALBA. 1993. A 3620-year temperature record from *Fitzroya cupressoides* tree rings in southern South America. Science 260:1104–1106.

MUTCH, L. S. AND T. W. SWETNAM. 1995. Effects of fire severity and climate on ring-width growth of giant sequoia after burning. Pp. 241–246 *in* J. K. Brown, R. W. Mutch, C. W. Spoon, and R. H. Wakimoto, (technical coordinators), Proceedings: symposium on fire in wilderness and park management, 30 March–1 April 1993, Missoula, Montana. USDA Forest Service General Technical Report INT-GTR-320.

STEPHENSON, N. L. 1994. Long-term dynamics of giant sequoia populations: implications for managing a pioneer species. Pages 56–63 *in* P. S. Aune, technical coordinator. Proceedings of the Symposium on Giant Sequoias: their place in the ecosystem and society, 23–25 June 1992, Visalia, California. USDA Forest Service Gen. Tech. Rep. PSW-151.

——— AND A. DEMETRY. 1995. Estimating ages of giant sequoias. Canadian Journal of Forest Research 25: 223–233.

STEWART, G. W. 1930. Big trees of the Giant Forest. A. M. Robertson, San Francisco, CA.

STOHLGREN, T. J. 1991. Size distributions and spatial patterns of giant sequoia (*Sequoiadendron giganteum*) in Sequoia and Kings Canyon National Parks, California. Technical Report No. 43, Cooperative National Park Resources Study Unit, University of California, Davis, CA. USDI National Park Service.

STOKES, M. A. AND T. L. SMILEY. 1968. An introduction to tree-ring dating. University of Chicago Press, Chicago.

SWETNAM, T. W. 1993. Fire history and climate change in giant sequoia groves. Science, 262:885–889.

WILLARD, D. 1994. Giant sequoia groves of the Sierra Nevada: a reference guide. Privately published by D. Willard, P. O. Box 7304, Berkeley, CA, 94707.